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SOLVING OUR WATER PROBLEMS: WATER RENOVATION AND REUSE

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SOLVING OUR WATER PROBLEMS--WATER RENOVATION AND REUSE

by

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**When the paper was prepared in November-December 1965, the Federal Water Pollution Control Administration was the Division of Water Supply and Pollution Control of the Public Health Service. Since that time an agency was created and transferred to the U. S. Department of the Interior.

Introduction

Aside from floods, our "water problems" are summed in two categories--water supply and water pollution. Most people recognize and probably agree to this simple dichotomy. Water resource planning has, historically, been concerned with one or the other of these problems. In a brief and very simplified outline, the two problem categories are as follows:

The Water Pollution Problem

Water pollution was first recognized as an insult to aesthetic sensibilities:

* from the unsightly, even revolting appearance of floating matter from sewage discharges,
* from the disagreeable odors directly from raw sewage effluents,
* or, further downstream, from streams which had become septic.

The initial solution was the use of simple gravity clarification and/or screening by which gross particulate matter is removed from raw waste water as sludge or skimmings. With use of this first stage or "primary" treatment, larger suspended solids could be removed and the tendency of a stream to become anaerobic or septic could be somewhat reduced. Lowered, dissolved oxygen levels downstream from waste outfalls, however, remained as the major type of water pollution problem.

Progressively, various types of filters, chemical additives and even electrochemical techniques were applied to municipal waste as second-stage or "secondary" treatment steps. When it became widely recognized that certain waste components accelerated the microbiological use of dissolved oxygen in streams, biological treatment, itself, became the accepted standard for secondary treatment. The biological treatment processes used today, such as oxidation ponds, trickling filters, and activated sludge, are simply deliberate attempts under controlled conditions to satisfy the biochemical oxygen demand (BOD) of a waste prior to its discharge to receiving waters.

Even to the present time, treatment of municipal wastes has been calculated to reduce the quantity of suspended, floating, and biochemically oxygen-demanding materials. Well operated primary-secondary plants remove up to 90 percent of these materials; also, such treatment may remove normally 90 percent of the bacteria, 50 percent of the total nitrogen (organic plus inorganic), perhaps 20 to 40 percent of the phosphorus, and only 5 percent of the total dissolved matter.

As civilization changes, so does the nature of water pollution. Suspended solids and BOD are no longer the only measures of waste loads. Other pollutants are of increasing concern: persistent organics, radionuclides, nutrients, inorganic salts, even heat. Even if the real nature of water pollution did not change, however, our increased understanding of pollutional effects and mechanisms would still alter our recognition of "what is pollution?" In this context, it is easy to recognize that the waste treatment technology of the present will not be adequate to meet the challenge of the future.

With respect to BOD, the generally-attainable 85 to 90 percent removal efficiency will not prevent some streams from being overwhelmed by oxygen-demanding pollution within the foreseeable future. Even now, a relatively small but increasing number of streams in the Nation (FIGURE 1)[1] have reached the stage when complete primary-secondary treatment is applied to every municipal discharge (industrial discharges are not considered here because comprehensive date are not available). In a much larger number of cases (FIGURE 2)[1] almost 90 percent of the volume of municipal discharges to streams now receives secondary treatment. On one hand, this a highly desirable and even comforting picture, but where serious pollution exists or is imminent as the result of municipal wastes in such streams, where do we go from here?

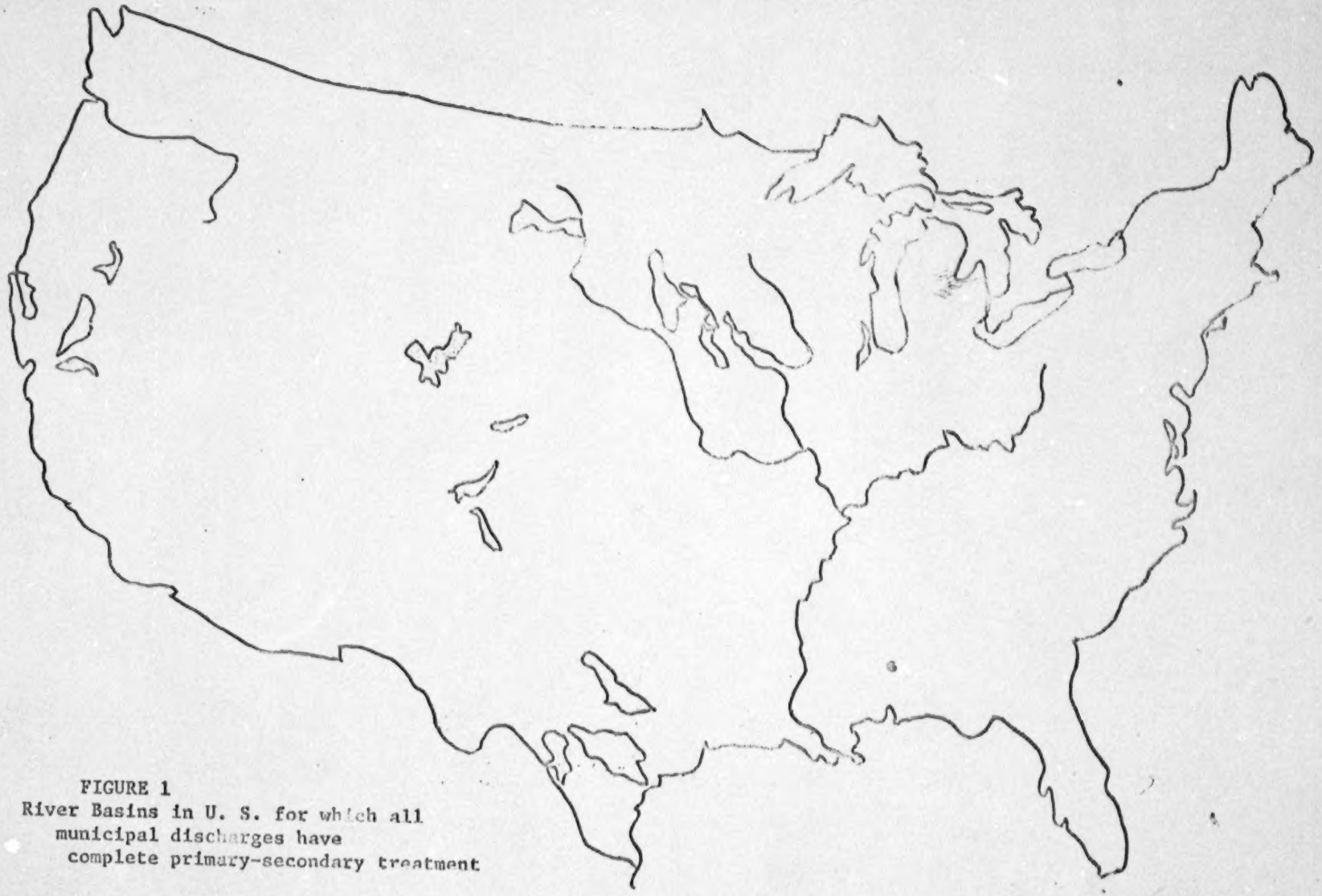

FIGURE 1
River Basins in U. S. for which all municipal discharges have complete primary-secondary treatment

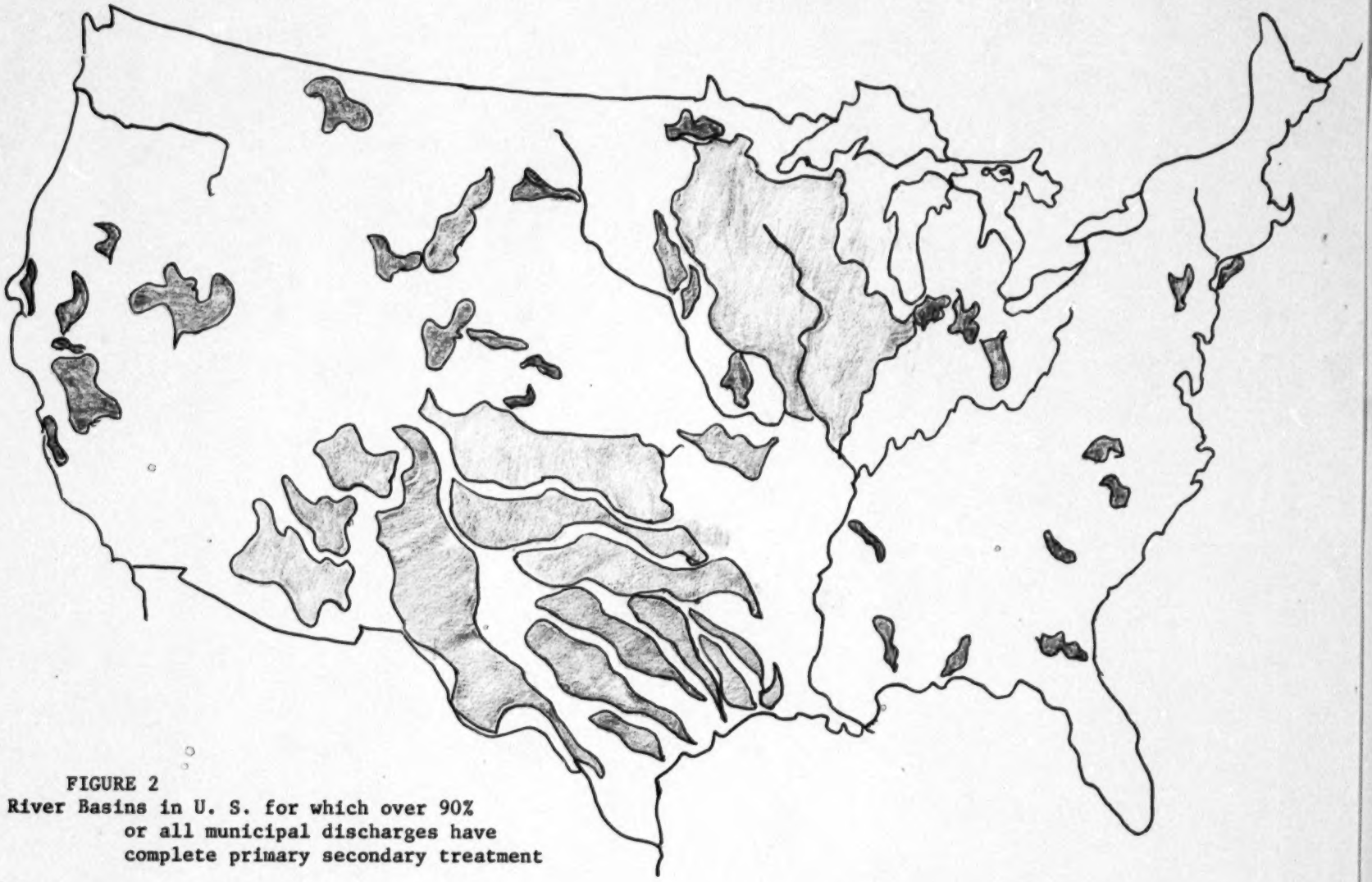

FIGURE 2
River Basins in U. S. for which over 90%
or all municipal discharges have
complete primary secondary treatment

When considering other parameters of pollution, the picture becomes more pessimistic. As an aid to understanding the trends in pollution loads to our streams, the municipal discharges of phosphates, total nitrogen, and refractory organics released to the Nation's waterways during the 20th century are estimated in FIGURES 3, 4, & 5. Refractory organics is defined as organic matter which is persistent in water and resists biological degradation.

Phosphates, nitrogen compounds, and refractory organics are significant because they can cause a variety of pollutional effects in the water; some are known, other are only suspected. Phosphorus and nitrogen, for example, can act as fertilizers in water and promote troublesome growth of algae or other aquatic plants. The pollutional effects of these substances can accelerate the natural aging of lakes and bring about major ecological changes; serious taste and odor problems can be created in downstream water supplies; sizable "fish kills: can be triggered.

The effects of refractory organics on water quality are not as well understood. Taste and odor, tainting of fish flesh, foaming, and fish kills have been attributed to such materials. Except for recognized toxicants, effects of refractory organics, if any, on human health are unknown.

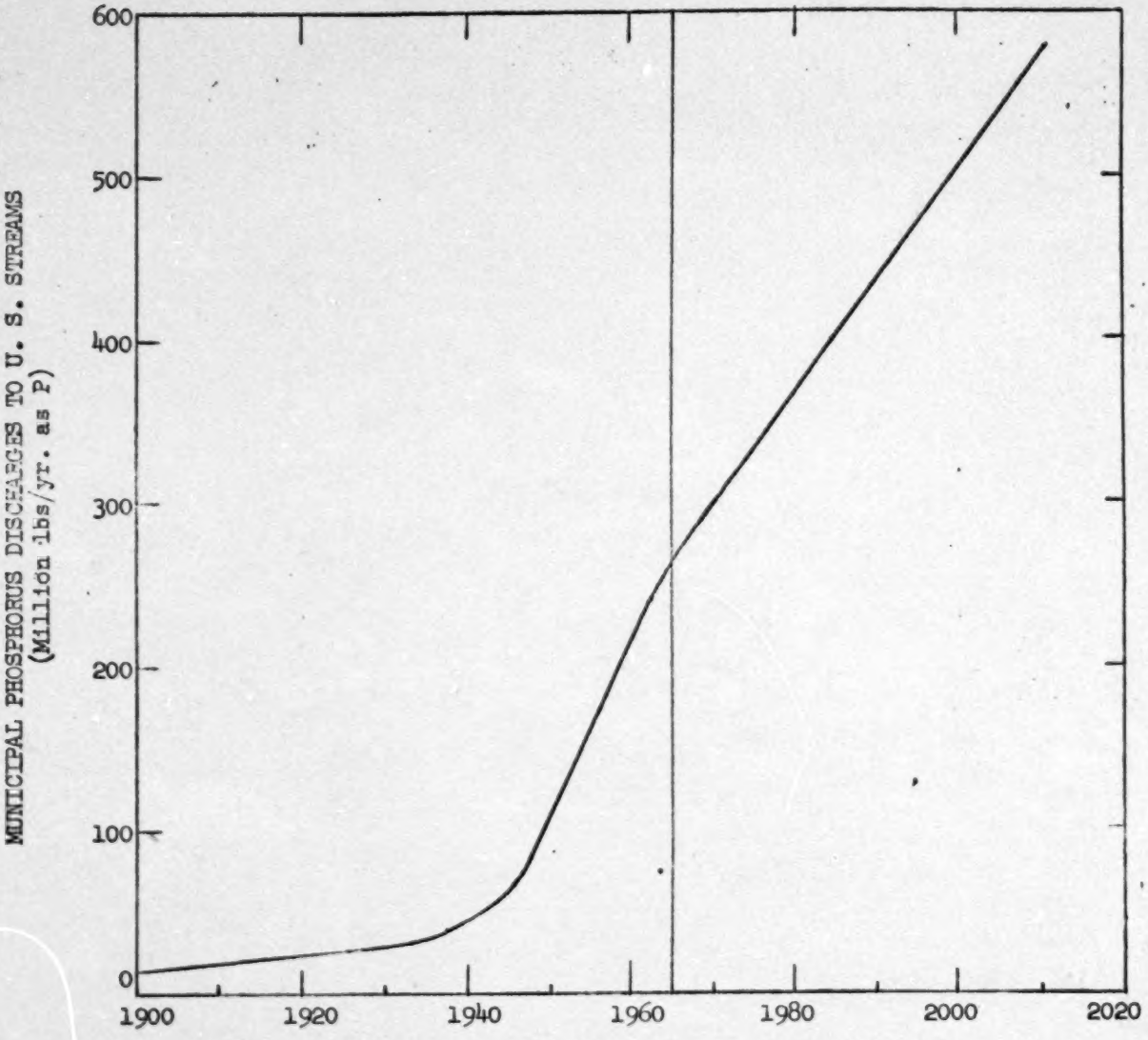

FIGURE 3

Estimate of phosphorus discharges to U. S. streams from municipal outfalls (1900-2020)

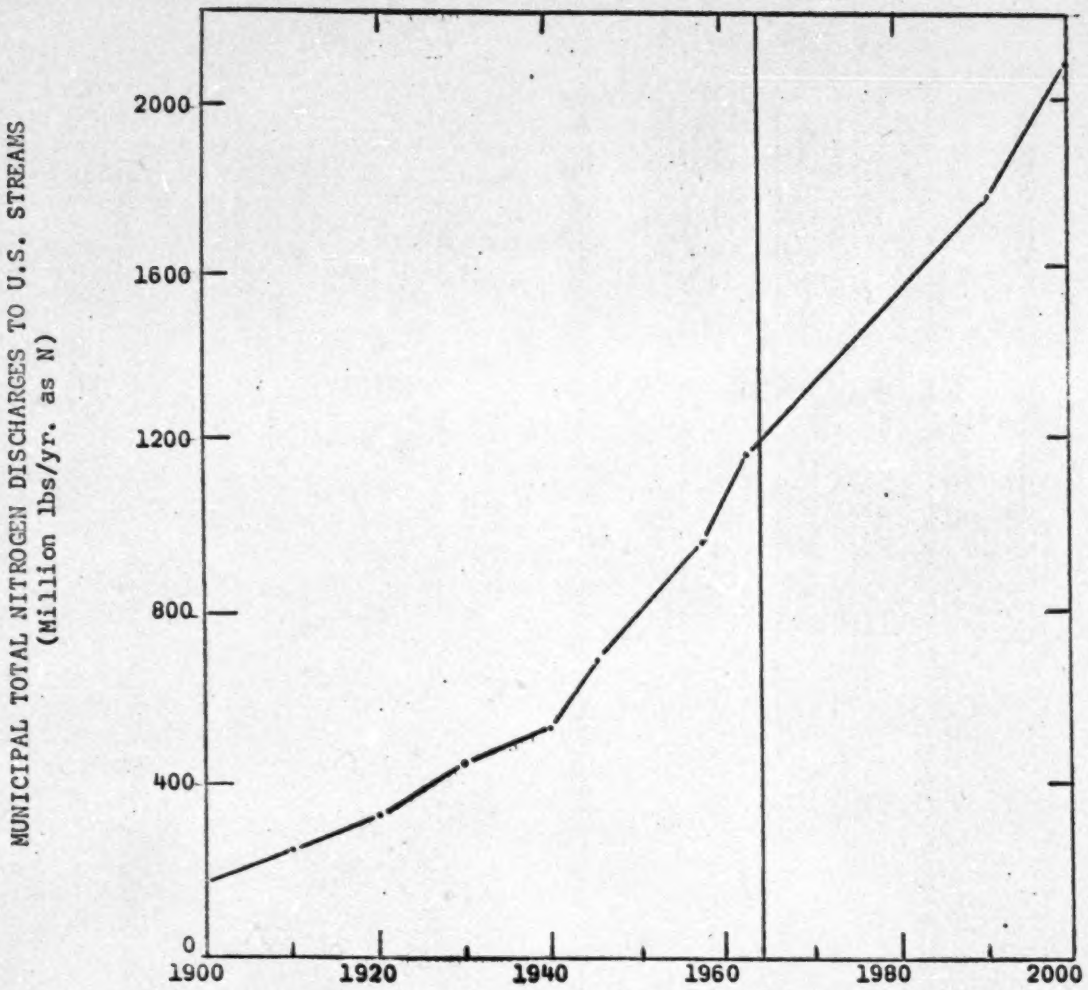

Figure 4

Estimate of total nitrogen discharges to U.S. streams from municipal outfalls (1900-2000)

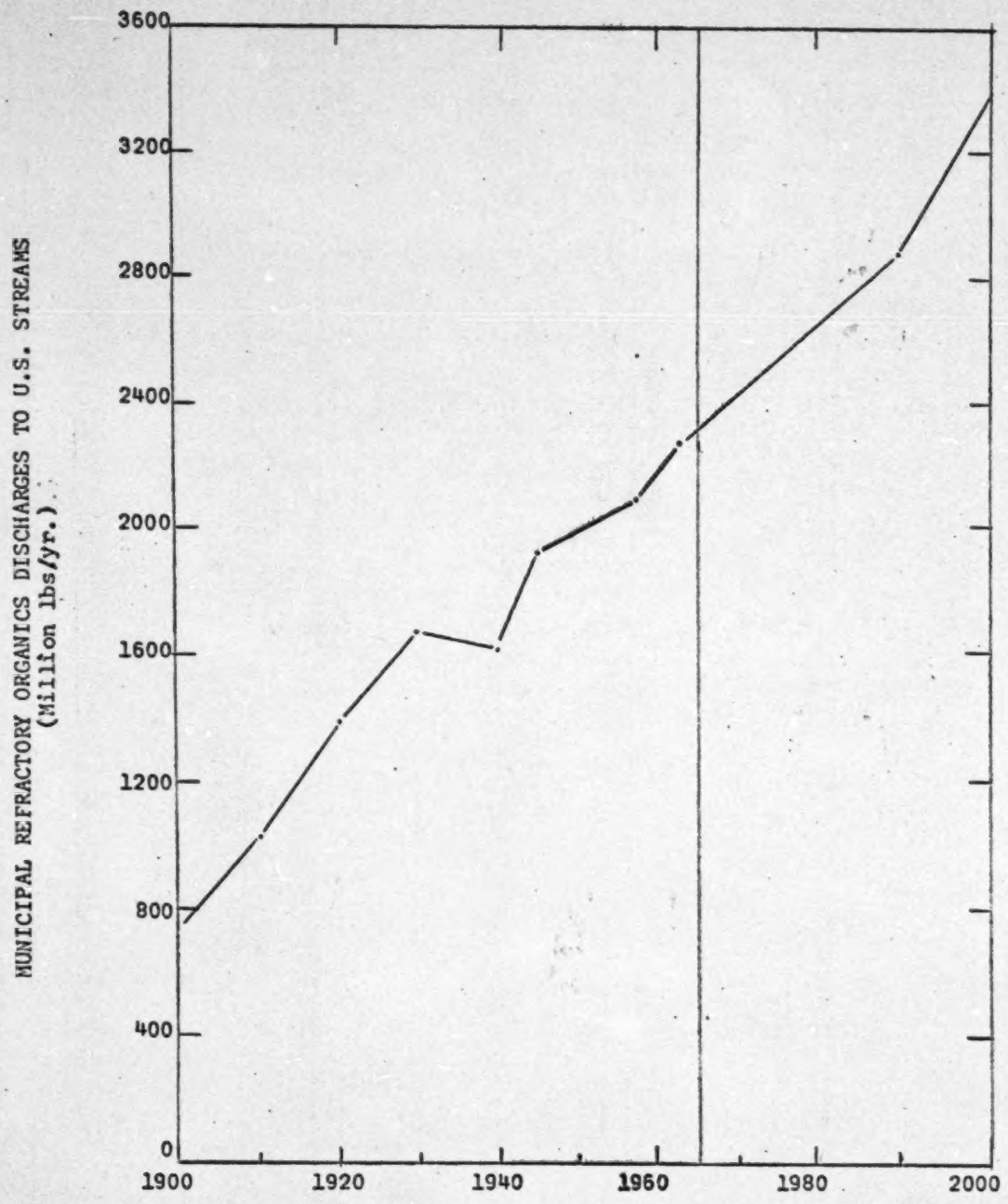

Figure 5

Estimate of refractory organics discharges to U.S. streams from municipal outfalls (1900-2000)

Even simple inorganic salts can pollute water if present in sufficient amounts. Public Health Service Drinking Water Standards specify that the total dissolved solids (TDS) in a drinking water supply should not be present in excess of 500 mg/liter. Yet, a single use of water by a municipality adds an increment of 300 to 400 mg/liter of such salts. Conventional waste treatment techniques are virtually ineffective in removing these salts.

Neglecting, for the moment, emerging problems from the treatment-resistant pollutants, what is the future picture of the classic "BOD pollution"? On a nationwide basis, the changes in BOD load discharged to our Nation's waters from municipal outfalls are estimated in Figure 6; This nationwide picture is potentially misleading, but is useful in developing several points. The portion of the curve representing 1900 to 1930 illustrates the increasing waste load due to the increasing population, in a period when secondary waste treatment plant installations were uncommon and even primary installations were not widely used. (In 1930 only about 15 percent of our population was served by primary treatment and less that 6 percent by secondary).

During the 1930's, treatment plant construction was accelerated in public works projects and, for the first time in the Nation's history, BOD discharges decreased. During World War II these gains were lost. During the post-war years, BOD discharges have remained almost constant.

Over the next 25 years, if we were to aim arbitrarily to apply complete primary-secondary treatment to all sewered municipal discharges, the national BOD load from municipal sources could be reduced by about 40 percent during this period.

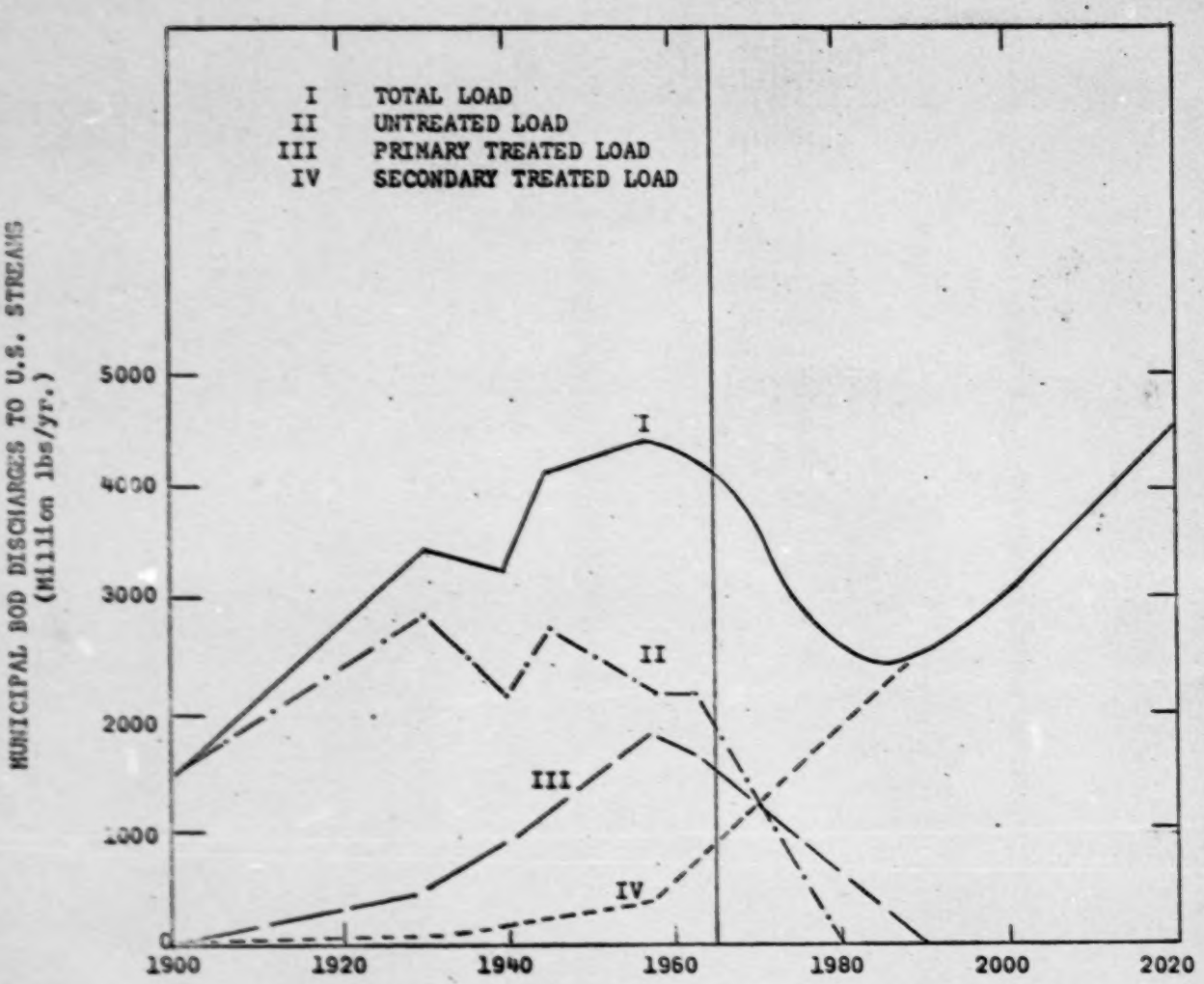

Figure 6

Estimate of BOD discharges to U.S. streams from municipal outfalls (1900-2020)

The first point, therefore, is that substantial improvements can be achieved simply through the more widespread application of existing waste treatment technology.

From 1990, the curve illustrates the second point: BOD discharges will inexorably increase due to expanding population despite the universal application of the most efficient waste treatment processes now conventionally available. By 2015, just 50 years from now, discharges would be again at present levels and would increase 2 to 3 percent per year. Furthermore, we will not be able to reduce or even to maintain present rates of discharge of pollutants for which conventional treatment is not as efficient as for BOD. (see FIGURES 3, 4, and 5).

THE WATER SUPPLY PROBLEM

The water supply problem is perhaps easier to quantify and is certainly easier to "document" by use of the many articles appearing in the popular press. Recently, the Saturday Review published "Our Crisis in Water;" Look printed "Are We Running Out of Water?"; U. S. News and World Report contained "Water Problem in the United States--What Can Be Done About It?"; and Time reported on "Water: Worldwide Use and Misuse." In the technical press, a large number of articles on our Nation's water supply problems have appeared. From Washington still other reports and testimony have emanated.

With this background of information, we do not need to develop more than a skeleton outline of the problem. First, it should be very clear to New Yorkers that water shortages occur not only in arid areas but also occasionally in normally water-rich areas of the world. It should also be clear that water supply problems may be more severe in regions of occasional shortage than in regions where such problems are an expected occurrence. Next, water supply can be a real problem in an area such as New York City even without a "northeast drought!" On Long Island, for example, water is pumped from the ground and the importing of water overland is becoming progressively more difficult and more expensive as the New York City metropolitan area grows and forms an ever-widening barrier to importation. What is happening on Long Island? Population, industry, and water demand are growing; ground water levels are falling; and salt water is progressively intruding into the presently used fresh water aquifers.

In regard to the nationwide picture of water supply, FIGURE 7 illustrates the rate of withdrawals of water for various uses during the 20th century. This graph implies that we have already run out of water. In fact, we ran out of water in 1957, when our withdrawal of fresh water exceeded our "dependable supply." By 1983 our withdrawal will equal our estimated <u>total</u> developable supply and we will <u>really</u> run out of water!

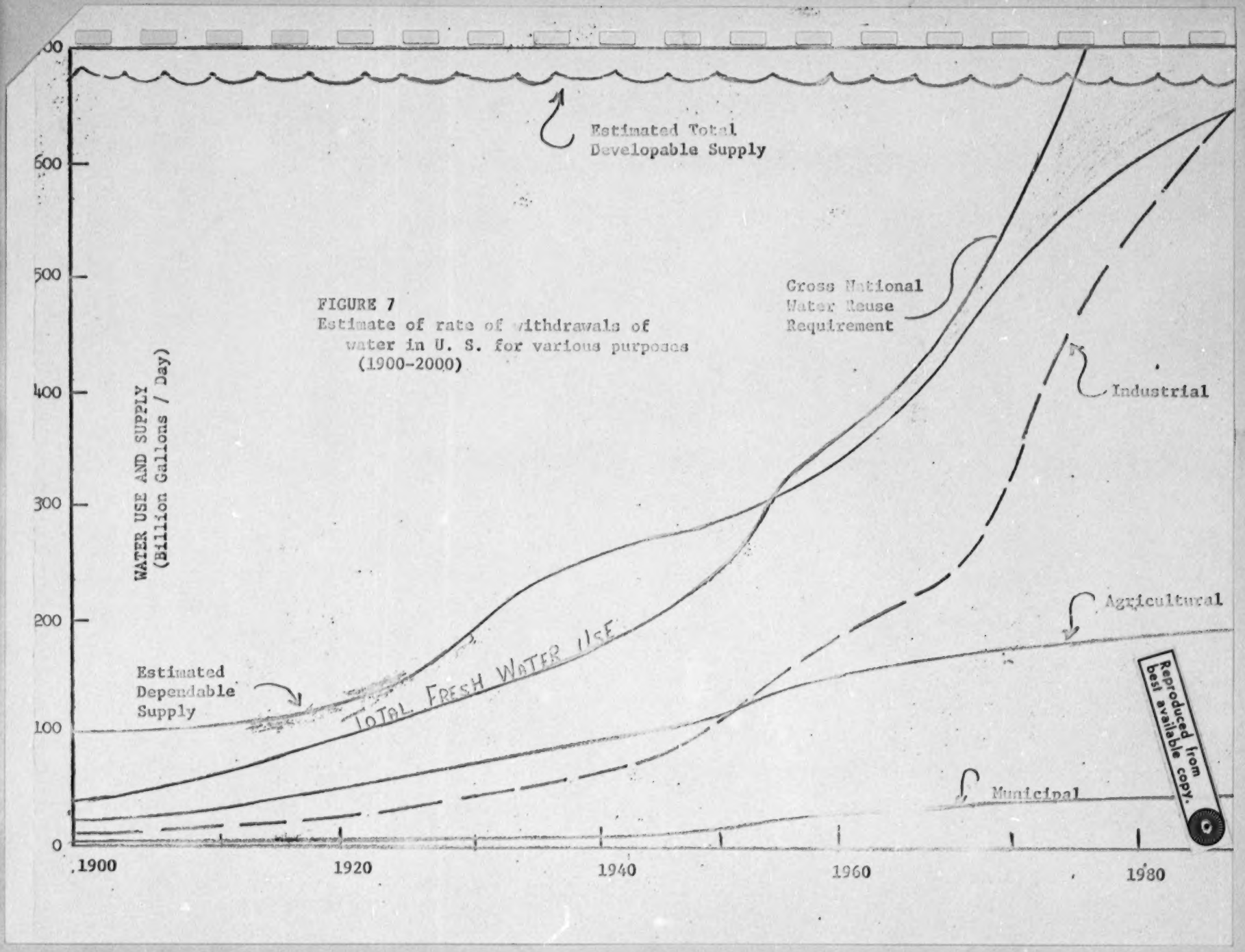

FIGURE 7
Estimate of rate of withdrawals of water in U. S. for various purposes (1900-2000)

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In spite of the obvious fallacies in the above statements, an amazing number of predictions of water doom have been based exactly on this fallacious projection. The truth is that our Nation as a whole is not running out of water and will not within the reasonably forseeable future. The simplest explanation is three-faceted:

1) neither our water supply nor our water needs are uniformly distributed geographically,

2) neither our supply nor our demand is uniformly distributed with time, and

3) all water withdrawn and used is not consumed; much of it is returned to our fresh water resource for reuse.

Water Pollution and Water Supply, Inseparable Problems

Accepting the concept of use and reuse, we begin to realize the relationships between water supply and water pollution and between water quantity and water quality. Every use of water imposes some change in its quality. These changes, no matter how severe, are inconsequential if the water is not used further. But, in almost every case, some type of reuse does occur. It may be reuse as part of a drinking supply, reuse as a habitat for fish and other aquatic life, or reuse only for aesthetic enjoyment. Reuse and multiple reuse of our water resources are common, everyday occurrences. On the broadest scale, man has been using and reusing the same volume of water on the earth since Creation; purification and reuse occur naturally through the hydrologic cycle. More to the point, reuse occurs quite naturally and unavoidably from city-to-city and factory-to-factory as water flows through our river systems to the ocean.

Recognizing the inevitability of reuse, deteriorations in water quality imposed by use become significant. If water quality is degraded to the extent that reuse is inhibited or impossible, then downstream water supplies are reduced as realistically as if the water had been consumptively used upstream. Water supply and water pollution, therefore, are inexorably intertwined.

In earlier days, "dilution" and "stream self-purification" were relied upon to remedy pollution, and the most readily available or most economical natural supplies of fresh water were tapped. During this century, biological waste treatment has been used to supplement dilution and self-purification for pollution control, and gradually deteriorating qualities of water supplies or more distant sources have been accepted.

Recently, we have begun to investigate methods to augment natural water supplies, such as desalination and weather modification, and to explore new and different techniques of waste water treatment. The "Advanced Waste Treatment" (AWT) techniques under investigation range from extensions of biological treatment methods capable of removing nitrogen and phosphorus nutrients to physical-chemical separation techniques such as adsorption, distillation, and reverse osmosis. These processes, can achieve essentially any degree of pollution control desired and, as waste effluents are purified to higher and higher degrees by such treatment, the point is reached where effluents become "too good to throw away." Such effluents can and will be deliberately and directly reused as agricultural, industrial, recreational, and even municipal supplies. This is water renovation: the simultaneous alleviation of both elements of our water problem dichotomy.

Water Renovation--Today's Capability

Under the 1961 amendments to the Federal Water Pollution Control Act, the Public Health Service has conducted its Advanced Waste Treatment Research Program. This Program, is "screening" about thirty treatment processes to assess their technical and economic feasibility. Several processes are now available for application; one was recently installed in full-scale municipal service. Several of the processes can even be operated in series to produce potable water from municipal waste water. For each of these processes, however, some degree of overdesign must still be incorporated to assure reliable performance: the higher the potential difficulty or hazard involved in performance failure, the higher the degree of conservation and overdesign that is required. The optimization of these processes to minimize capital and operating costs must await further full-scale testing and improvements in design, materials, and equipment by consultants and equipment manufacturers.

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After removal of colloidal and suspended solids, the soluble refractory organics may be very efficiently removed by contact with activated carbon granules. Such carbon will adsorb 20-30 percent of its own weight in mixed organics from waste water when used in counter-current flow fixed-bed contactors. Using a mass velocity of 7 gal/min-ft.^{2}, and a contact time of 40 minutes will remove more than 98 percent of both BOD and total organic matter. To minimize cost, the activated carbon should be regenerated and reused. Fortunately, the thermal regeneration of activated carbon following saturation with actual waste organics is possible. Fifteen successive saturation-regeneration cycles have been performed with satisfactory regeneration efficiencies. This process is being studied in a 300,000 gpd pilot plant at Pomona, California, under a joint research project of the Public Health Service and the Los Angeles County Sanitation Districts. The process also has been used since last summer in actual municipal service in a 2.5 mgd plant of the South Tahoe Public Utility District at Lake Tahoe, California.

At a scale of 10-20 mgd, the adsorption plant capital costs should be about $.15/daily gallon capacity and at 100 mgd, about $.09/daily gallon. Operating costs, including 20-year capital amortization at 6 percent interest, should be less than $.10/1,000 gallons for a 10-20 mgd plant and about $.06/1,000 gallons at the 100-mgd scale.

Except for dissolved inorganic salts added during use, a municipal waste water subjected to the foregoing treatment steps in series will be restored to a chemical quality generally comparable to that before use. As stated earlier, the salts added during one passage through a municipal system normally total about 300-400 mg/l (TABLE I). Since many water supplies contain these same dissolved salts at approximately this concentration, one municipal use of water generally doubles the salt content. Fortuitously, a single-pass electrodialysis reduces the concentration of dissolved inorganic solids by 40-50 percent, the percentage required to remove the increment of mineral pollutants added during use.

Extended bench-scale tests and operating pilot-scale studies at 75,000 gpd have established that the power requirements for this service are only 6-10 kwh/1,000 gallons. For "typical" waste waters (TABLE I), polarization can be avoided if a current density-to-concentration ratio of 750 $(ma/cm^2)/(g.eq./l.)$ is not exceeded. Under these conditions, effective cell-pair area requirements are less than 0.004 $ft.^2/gpd$ and concentration ratios greater than 10:1 can be readily achieved with proper pH control; ratios as high as 50:1 have been attained.

Average Composition of Municipal Secondary Effluent

Table I

Component	Average concentration in secondary effluent (mg/l.)	Average increment added during water use+ (mg/l.)	Average increment added during water use+ (lb/day 1000 pop.)
Gross organics	55	52	64
Bio-degradable organics (as BOD)	25	25	31
Methylene blue active substance (MBAS)*	6	6	7
Na^+	135	70	86
K^+	15	10	12
NH_4^+	20	20	25
Ca^{++}	60	15	18
Mg^{++}	25	7	9
Cl^-	130	75	92
NO_3^-	15	10	12
NO_2^-	1	1	1
HCO_3^-	300	100	120
$CO_3^=$	0	0	0
$SO_4^=$	100	30	37

Table I (continued)

Component	Average concentration in secondary effluent (mg/l.)	Average increment added during water use+ (mg/l.)	Average increment added during water use+ (lb./day 1000 pop.)
$SiO_3^=$	50	15	18
$PO_4^=$	25	25	31
Hardness ($CaCO_3$)	270	70	86
Alkalinity ($CaCO_3$)	250	85	100
Total dissolved solids	730	320	390

* apparent alkyl benzene sulphonate.

+ Concentration increase from tap water to secondary effluent.

The feed must be carefully pretreated to operate successfully the electrodialysis stacks in this service. With suspended solids removed to avoid plugging and with dissolved organics removed to avoid membrane fouling, electrodialysis of waste water is relatively straightforward although very recent results indicate some complications from microbiological forms. In tests to date, long-term ion removal has been largely non-selective. The concentration of each ion present is reduced by roughly the same fraction. This is fortunate because generally uniform removal is just what is required to provide water of satisfactory quality for most purposes of reuse. One exception exists. Ammonia can be tolerated in municipal water supplies and in many industrial supplies only to a few parts per million. Since typical municipal waste water contains 20 mg/l. NH_4^+, the removal of 90-95 percent is required. To achieve this by conventional electrodialysis is prohibitively costly. The answer appears to be in operating secondary biological treatment under nitrifying conditions so that NH_4^+ is almost completely converted to NO_3^-. For simple discharge to a stream and when nutrients are a pollution problem, the nitrate levels present may be undesirable, but, for reuse as a municipal supply, the NO_3^- concentration is not of concern in most cases.

Capital costs for electrodialysis equipment should be less than $.15/daily gallon capacity at 10-20 mgd and under $.11/daily gallon capacity at 100 mgd. Unless serious unforeseen difficulties are encountered in pilot-scale tests, total operating costs should not exceed $.15/1,000 gallons at 10-20 mgd and should be about $.10/1,000 gallons at 100 mgd.

The type of water renovation sequence described above is an existing technology within our present capability. On September 8, 1965, Dr. Donald F. Hornig, the President's Special Assistant for Science and Technology, testifying before the Senate Interior and Insular Affairs Committee, stated that:

> "At my request, the Department of Health, Education and Welfare has just completed a feasibility analysis of a 100-mgd waste water purification plant which could be added to a secondary sewage treatment plant of the kind now used in New York City and northern New Jersey. Their report indicates that such a plant could be built for $33 million and would produce potable water at a cost of about 16¢ per 1,000 gallons. The Department of Health, Education, and Welfare has had a modest research program in waste water purification underway and the plant they considered would use the best proven, presently available technology. Almost certainly these costs could be reduced still further through a R & D program. The suggested plant employs aeration, chemical coagulation and sedimentation, carbon adsorption and chlorination to purify the effluent from a secondary sewage treatment plant. If the product water is mixed with water from other sources in a large system no further treatment is necessary. For a completely closed system in which all water is recycled a buildup of salinity would occur and a desalting unit would be needed. Because of the very low salt content, electrodialysis could be used and the additional cost would be only a few cents per 1,000 gallons depending on the amount of salts to be removed. The costs quoted above include cost of land, treatment, and pumping costs to return the water to the distribution system. Direct delivery of purified waste water to a city distribution system is possible and can be completely safe. If it is too unattractive aesthetically, the purified waste water can be used for recreational and decorative lakes, watering parks and golf courses, industrial processes, or can be recharged to the groundwater. It must be noted, however, that there is very little practical difference between purification and direct reuse of waste water and the present widespread practice of discharging of wastes to a river from which a downstream city takes it water supply."

Water Renovation--Tomorrow's Promise

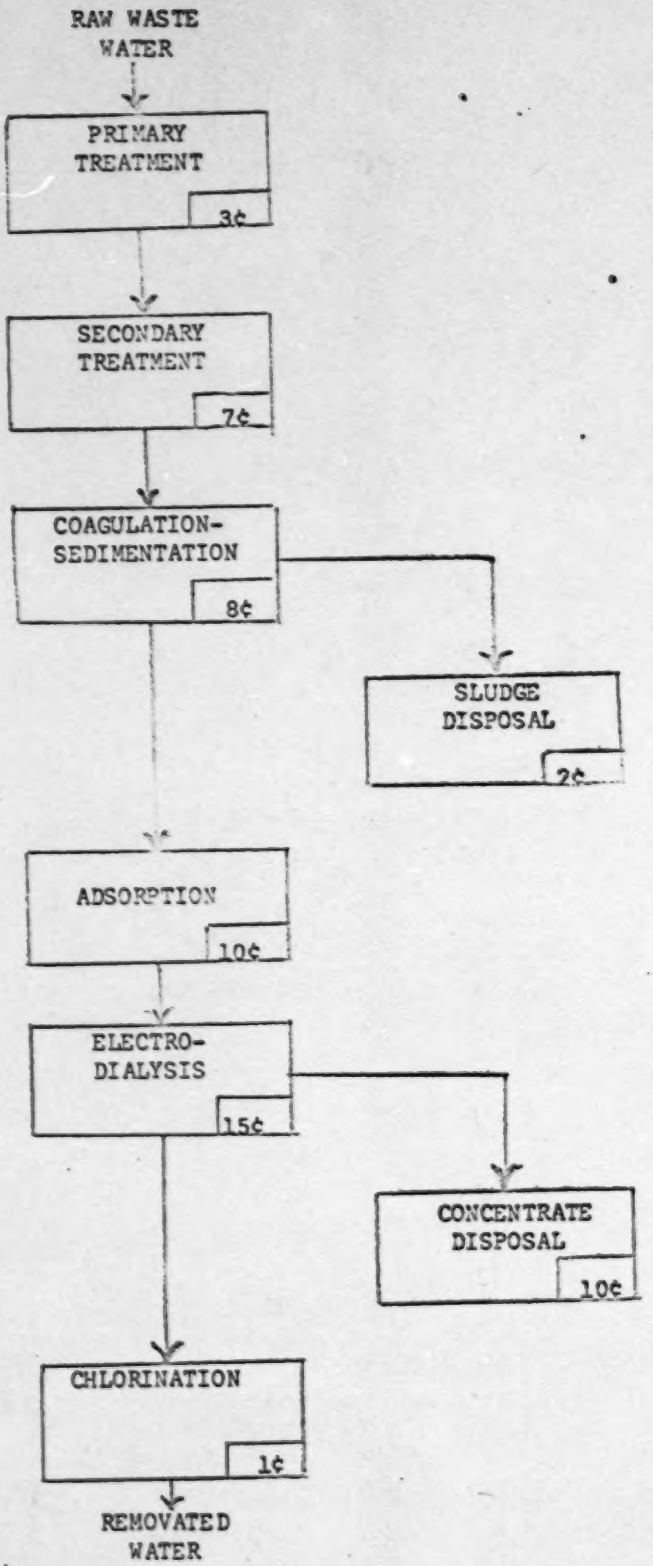
Only a year or so ago, the plan Dr. Hornig referred to could not have been offered. Today it can be proposed with confidence. Even with its reality, it should be regarded only as an "early model" of future versions which will be more efficient and more economical. A whole range of new techniques are now being studied, not only by the Federal Government, but by State and local governments, by universities, and by industry.

One process, bio-denitrification, uses specially acclimated microorganisms to reduce nitrates to elemental nitrogen under certain process conditions. Another, foam separation, takes advantage of surface adsorption phenomena to make beneficial use, under controlled treatment conditions, of the hitherto unwanted billowy foam so common in many waste waters. Chemical oxidation of complex and unknown organic contaminants with hydrogen peroxide, ozone, or even hydroxyl free radicals generated by corona discharge is being considered. Phase separations such as distillation, freezing, and gas hydration are under study as is perhaps the best "dark horse" candidate for total waste water purification--reverse osmosis.

Our long range objective in this research is to provide the necessary treatment systems for attaining any degree of waste treatment which may be required and at the minimum feasible cost. Significantly, the word "systems" is used. Rarely will an advanced waste treatment process stand alone. Instead, systems of individual processes in series or in parallel will be required to meet particular needs. Included in the systems must be one or more of a variety of ultimate disposal processes. These processes are methods for permanent, non-pollutional disposal of the inevitable sludges and waste concentrates generated by the separation processes used. These disposal techniques may include incineration, digestion, or wet oxidation of organics; conveyance of various sludges and solid residues to the ocean or remote dump sites; and deep-well injection of brines into porous strata. Possible beneficial uses of waste concentrates as soil conditioners, fertilizers, or chemical raw material should be included in the ultimate disposal category.

Two general system configurations can be used. In the series-type system already described (FIGURE 8), the total flow passes through all processes in sequence. Each process contributes to quality improvement. In the system pictured, the conventional primary treatment removes material that readily settles or floats. The secondary biological step removes the readily biologically-degradable impurities. Coagulation-sedimentation, in the third position, eliminates suspended solids and colloids. Carbon adsorption removes residual dissolved organics. Electrodialysis returns the dissolved minerals level to an acceptable value. Finally, chlorination provides a positive disinfection step.

The same result can be obtained with a parallel-flow system (FIGURE 9). Here, primary and secondary treatment, coagulation-sedimentation, adsorption, and chlorination function as described above. Demineralization is achieved by a "total removal" process, that is, evaporation plus distillate "polishing", which handles only about half of the total flow. Following this step, the completely purified water (the distillate) is blended with the flow from which all impurities except the salts have been removed.



POSSIBLE SERIES SYSTEM COST AT 10-20 mgd

3
+
7
+
8
+
2
+
10
+
15
+
10
+
1
56¢/1000 gal.

FIGURE 8. GENERALIZED WATER RENOVATION SYSTEM, SERIES FLOW.

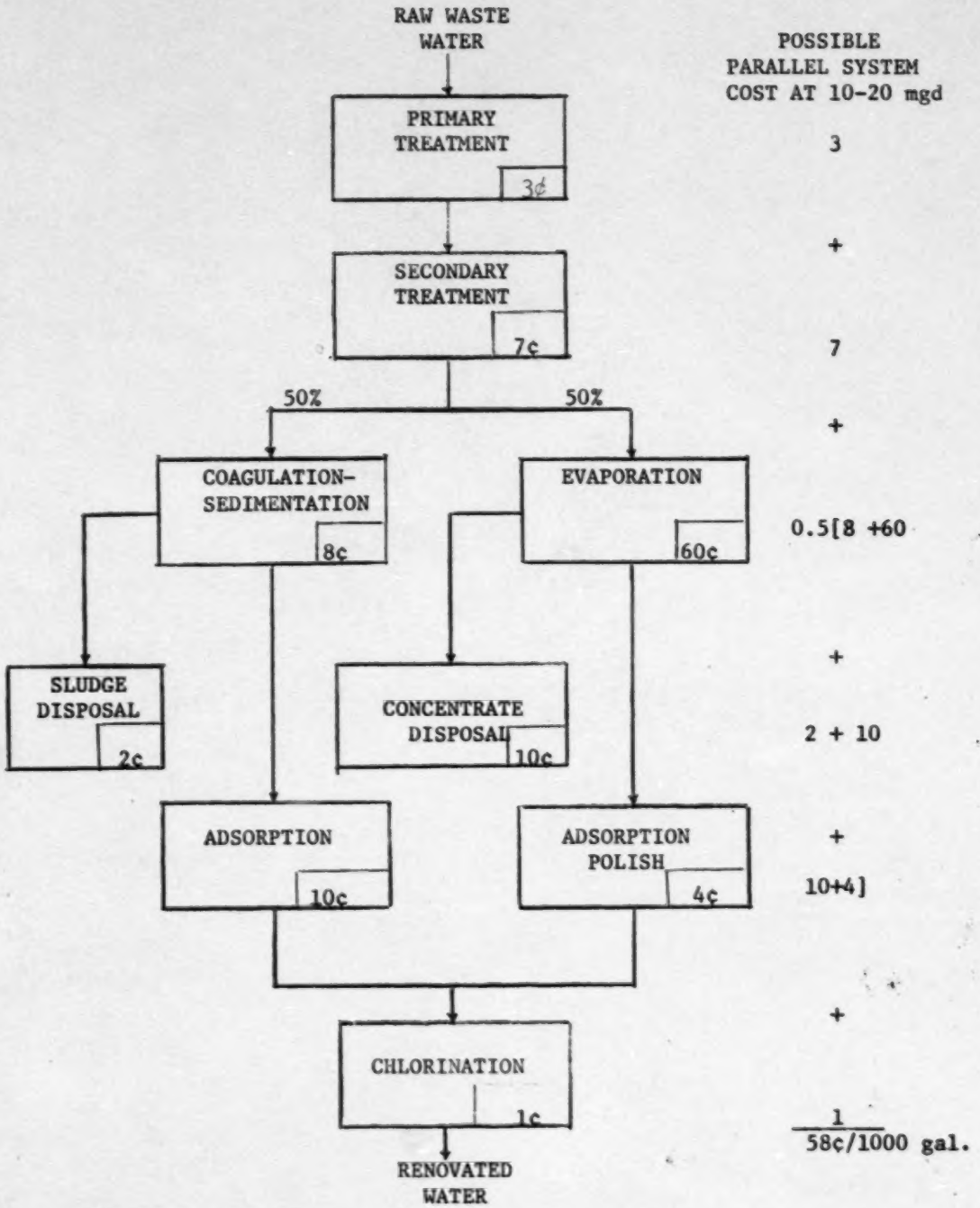


FIGURE 9
GENERALIZED WATER RENOVATION SYSTEM, PARALLEL FLOW.

In FIGURES 8 and 9 the unit costs are estimated for both a series-flow and a parallel-flow system, at a scale of 10-20 mgd. First, the total system costs are so similar ($.56 vs. .58/1,000 gallons) that neither system can be omitted in favor of the other. Second, the costs of conventional and advanced treatment steps can be compared.

In contrast to the present cost of $.10/1,000 gallons for primary-secondary treatment (FIGURE 8), coagulation-sedimentation, which very efficiently removes suspended solids and phosphates, costs an additional $.08- .10/1,000 gallons (certain biological treatment modifications may be able to remove up to 80 percent of the phosphates at a lower cost). If the adsorption step were incorporated to eliminate BOD and persistent organics, the additional cost is raised to $.18-.20/1,000 gallons. This total waste treatment cost is almost three times our present level.

To complete the renovation with electrodialysis would add another $.25/1,000 gallons, to give a total renovation cost over five times the cost of existing waste treatment. Clearly, this is not an illustration of "something for nothing." Yet, the cost picture is not really so dark. First, the AWT costs quoted are conservatively high and probably would not be exceeded under normal circumstances. Second, the costs should be reduced significantly as research and development programs bring us closer to optimum designs. Third, substitute processes now being investigated may reduce costs sizably. The powdered carbon process, for example, could conceivably replace at half the cost, both coagulation-sedimentation and granular carbon adsorption, which cost .18-.20/1,000 gallons, or half the cost.

Finally, AWT costs are perhaps better and more fairly compared with the combined costs of both conventional water supply and waste treatment costs, not with waste treatment costs alone. Water supply and waste treatment costs, based on historical data and including source development, transmission, water treatment, and waste treatment, average about $.23/1,000 gallons in the U. S. and nearly $.30/1,000 gallons in prevailing high cost areas of the country.[2] Future average costs for extending conventional treatment and for augmenting water supplies will undoubtedly be higher.

Now, what could be the physical impact of waste water renovation on our future water pollution and water supply problems? To derive an answer, Figures 3, 4, 5, and 6 were redrawn in Figure 10, which assumes that during the next 25 years the AWT processes now available will be applied to every municipal effluent in the land. Municipal BOD pollution, instead of facing only a temporary respite and rising again to present levels just after the year 2000, would be very close to fulfilling President Johnson's recent pledge to "doom water pollution in this century." With respect to phosphate and refractory organic loads entering our streams, not even the respite could be expected with today's treatment methods. However, with AWT, the first reductions in history could be accomplished. For nitrogen forms, even available AWT processes will not be highly effective. Processes still in development must meet this need.

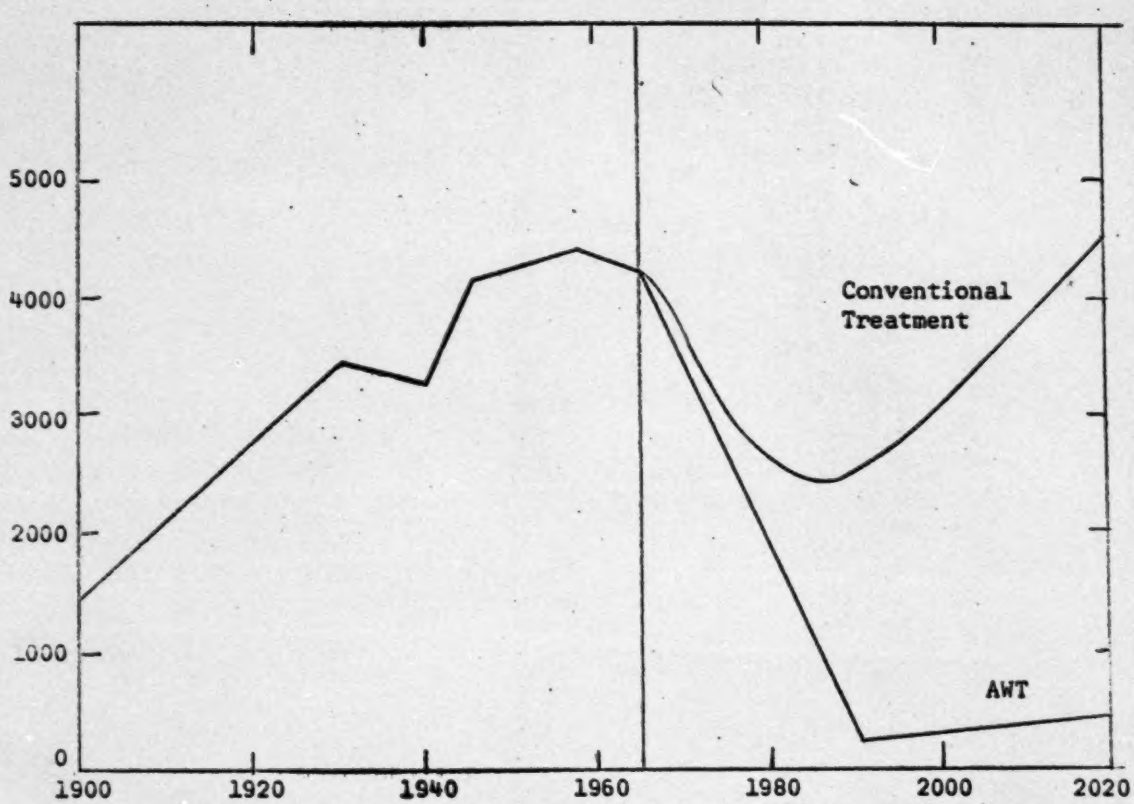


Figure 10 (a)

Potential impact of AWT on municipal discharges of BOD to U.S. streams

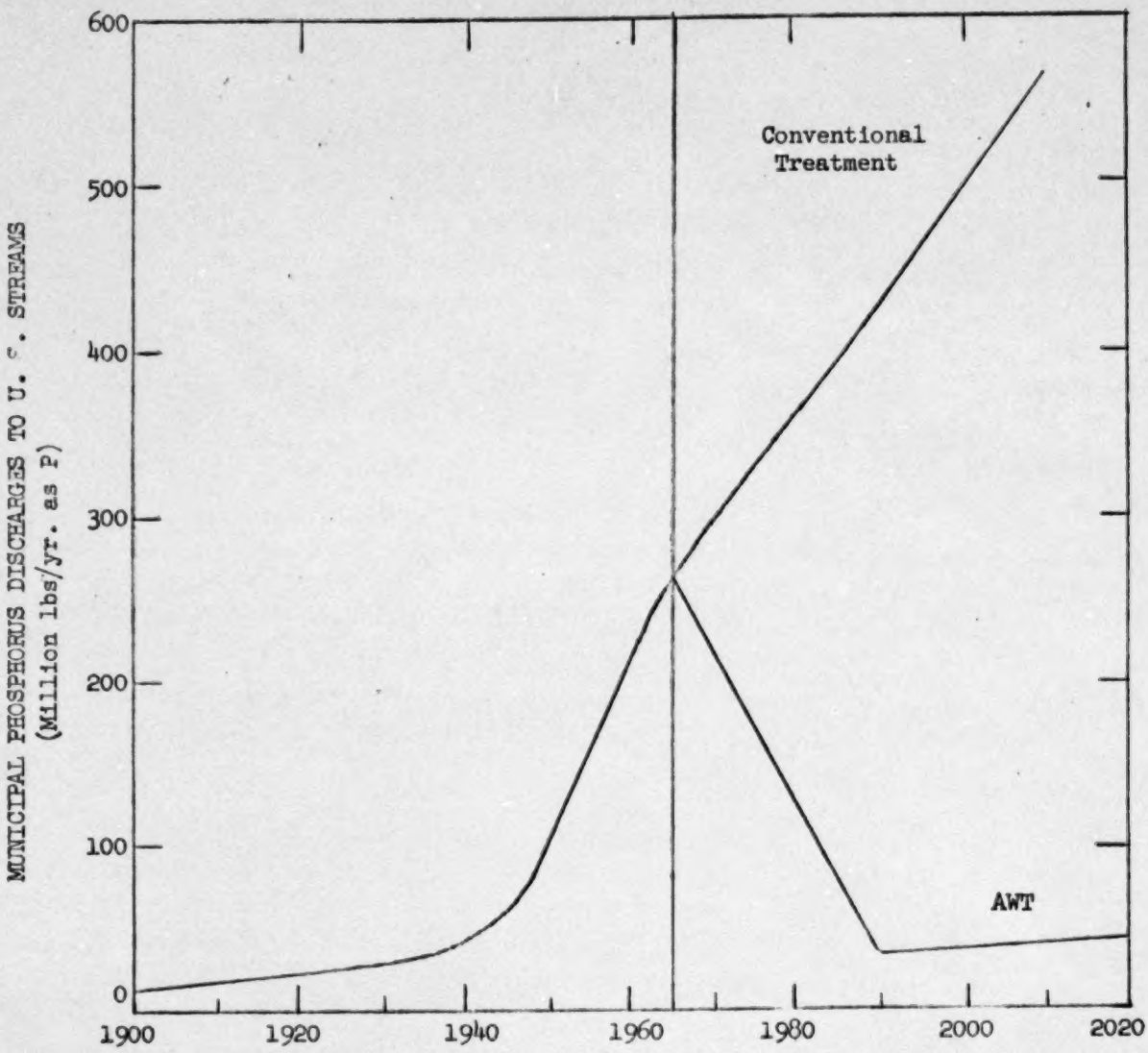


FIGURE 10 (b)

Potential impact of AWT on municipal discharges of phosphorus to U. S. streams

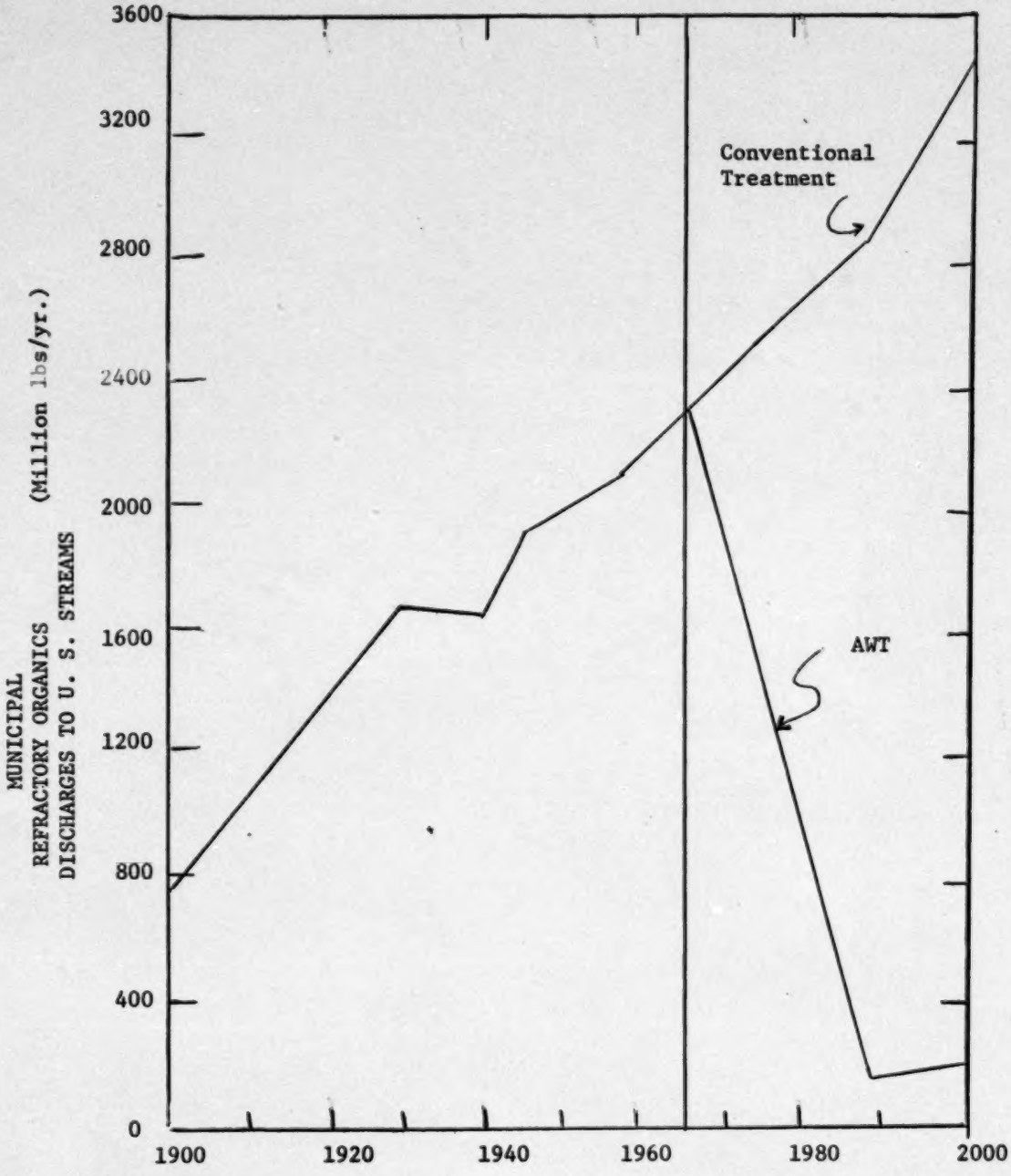


FIGURE 10 (c)

Potential impact of AWT on
municipal discharges of refractory organics
to U. S. streams

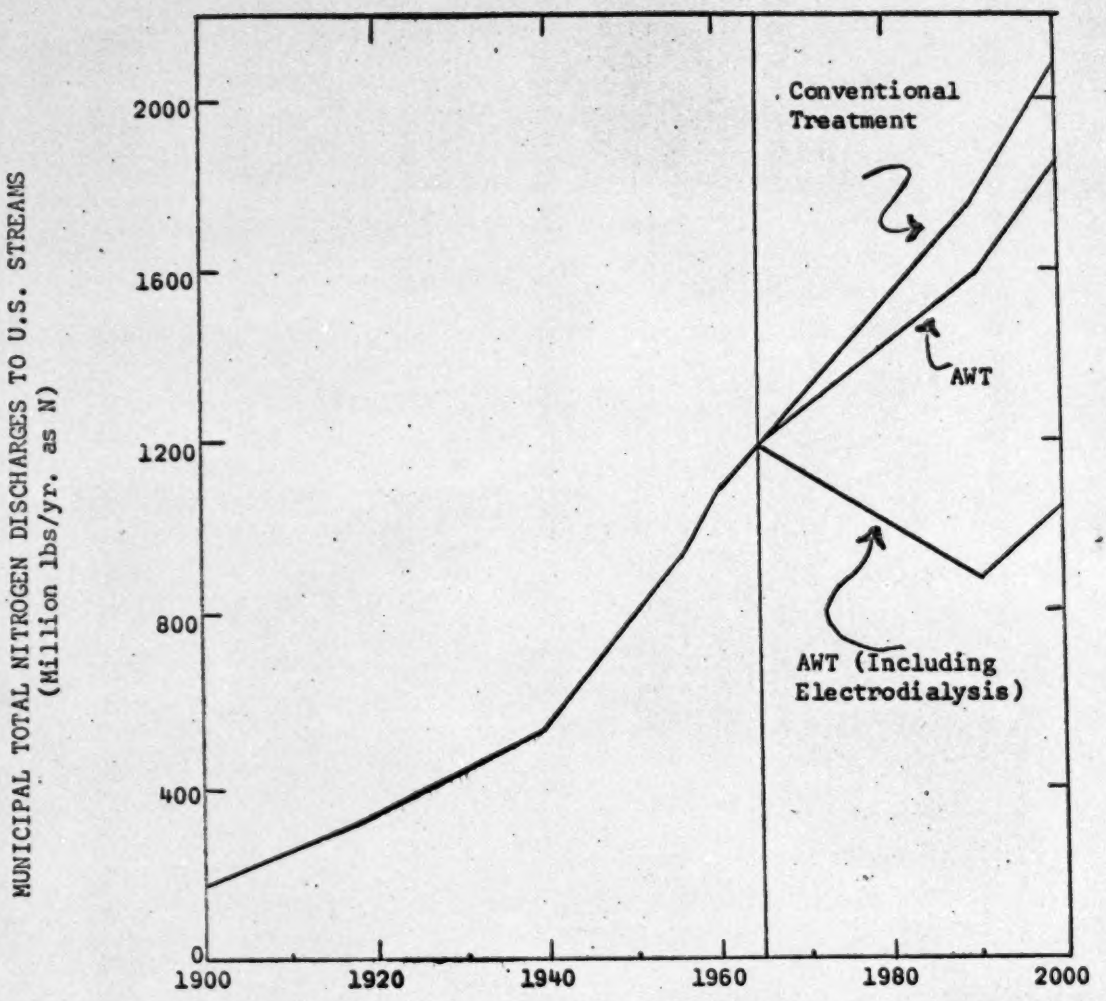


Figure 10 (d)

Potential impact of AWT on municipal discharges of nitrogen to U.S. streams

Unfortunately, the gross impact of water renovation on water supply cannot be so readily measured on any nationwide basis because of the present appreciable natural reuse of our fresh water resource. Possibly a more satisfactory picture can be obtained by focusing attention on an individual water user. If New York City, for example, were to renovate 80 percent of the water used by the city, the existing upland fresh water supply, of some 1,200 mgd would be effectively enlarged five times. This same general principle applies to all municipal as well as industrial supplies. Irrigation supplies could not be enlarged to this extent because of the high consumptive losses involved.

A third major impact of water renovation on our impending water resources situation results from another, less well understood relation between water supply and water pollution. We refer to the "low flow regulation" concept, that is, the storage and later release of upstream water to dilute downstream waste discharges. Here, a water supply requirement, although not a withdrawal requirement, is created directly as the result of water pollution.

Most people are startled by projections[3] that dilution alone (of municipal and industrial BOD waste discharges, all treated to 90 percent efficiency) will require more water than for any other single use! In 1980, for example, the required flow magnitude would be about 300 bgd and by 2000, over 475 bgd. Actually the picture is vastly more complex than this and a detailed discussion is beyond the scope of this paper. Briefly, with 95 percent BOD removal, the calculated dilution volumes would be only one-half of those above and with 99 percent treatment, only one-tenth. The conclusion[3] "that theoretical dilution water requirements for these wastes will not go to zero as treatment efficiency approaches 100 percent," is in error when physical-chemical treatment, and not extended biological treatment, is assumed.

In closing, we refer to several recent advertisements by an industrial firm specializing in water treatment chemicals. They ask the questions:

"Would you bathe a baby in secondhand water?" "Are you rinsing the salad greens in secondhand water?" "Would you brew your morning coffee with secondhand water?"

The answer to all of these questions, of course, is "YES" because that's exactly what most people do. Is "Solving Our Water Problems--Water Renovation and Reuse" really so startling after all?

Acknowledgement

The authors wish to acknowledge the assistance of Mr. Charles F. Walters of the Division of Water Supply and Pollution Control in preparing the estimates of municipal waste discharges shown in figures 3, 4, 5, and 6 and described in detail in Appendix A.

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APPENDIX

ESTIMATING MUNICIPAL DISCHARGES OF BOD, TOTAL NITROGEN, PHOSPHORUS AND REFRACTORY ORGANICS TO U.S. STREAMS

by
Charles F. Walters

The following nine assumptions were used in estimating the municipal discharges of various materials to streams in the United States (TABLE 3). The formulas used to estimate each of the four components considered are described after the pertinent assumptions.

1) It was assumed that all sewered municipal effluents are discharged to U. S. Streams.

2) It was assumed that by 1980 the discharge of raw municipal wastes will have ceased and that by 1990 the entire sewered population will be serviced by primary-secondary treatment. For the period 1900-1962, the sewered populations receiving "no treatment," $(SP)_{on}$, "primary treatment," $(SP)_{pn}$, and "secondary treatment," $(SP)_{sn}$, were derived from references 4-8.

3) It was assumed that the waste treatment efficiencies for various materials are those shown in TABLE 2. The fraction (f) of each material remaining in the effluent discharge, that is, $f = 1 - \frac{\text{treatment efficiency}}{100}$, is also given.

BIOCHEMICAL OXYGEN DEMAND (BOD)

4) Daily domestic BOD contribution, p_{BOD}, is 0.167 lbs./capita-day (a constant).

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5) To account for the increase in industrial wastes handled in municipal sewerage systems between 1900 and 2000, a varying ratio of "industrial plus domestic BOD" to "domestic BOD" was used. This was sometimes expressed as "PE/capita." Based on PE/capita figures for 1900, 1970 and 1980, as given in reference 11, and an assumption of PE/capita - 1.1 in 1930, a curve was prepared as shown in FIGURE 11. This curve was extrapolated to the year 2000 at a constant PE/capita of 1.75.

The amount of BOD discharged to U. S. streams from municipal outfalls for any year, n, was estimated from the formula:

$$(\text{lbs BOD discharged per year})_n = 365\, P_{BOD}\, (\text{PE/capita})_n\, [(SP)_{on} f_{oBOD} + (SP)_{pn} f_{pBOD} + (SP)_{sn} f_{sBOD}]$$

TOTAL NITROGEN

6) Assumed values for annual total nitrogen per capita loadings in raw municipal sewage (P_{TN}) between 1900 and 2000 were obtained from references 4, 12, 13, and 14. The data were plotted and an "average" curve was drawn and extrapolated as shown in FIGURE 11.

The amount of total nitrogen discharged to U. S. streams from municipal outfalls for any year, n, was estimted from the formula:

$$(\text{lbs. total nitrogen discharged per year})_n = (P_{TN})_n [(SP)_{on} f_{oTN} + (SP)_{pn} f_{pTN} + (SP)_{sn} f_{sTN}]$$

PHOSPHORUS

7) Assumed values for annual phosphorus per capita loadings in raw municipal sewage (P_p) between 1900 and 2000 were obtained from references 4, 13, 15, 16, 17, and 18. The data were plotted and an "average" curve was drawn and extrapolated as shown in FIGURE 11.

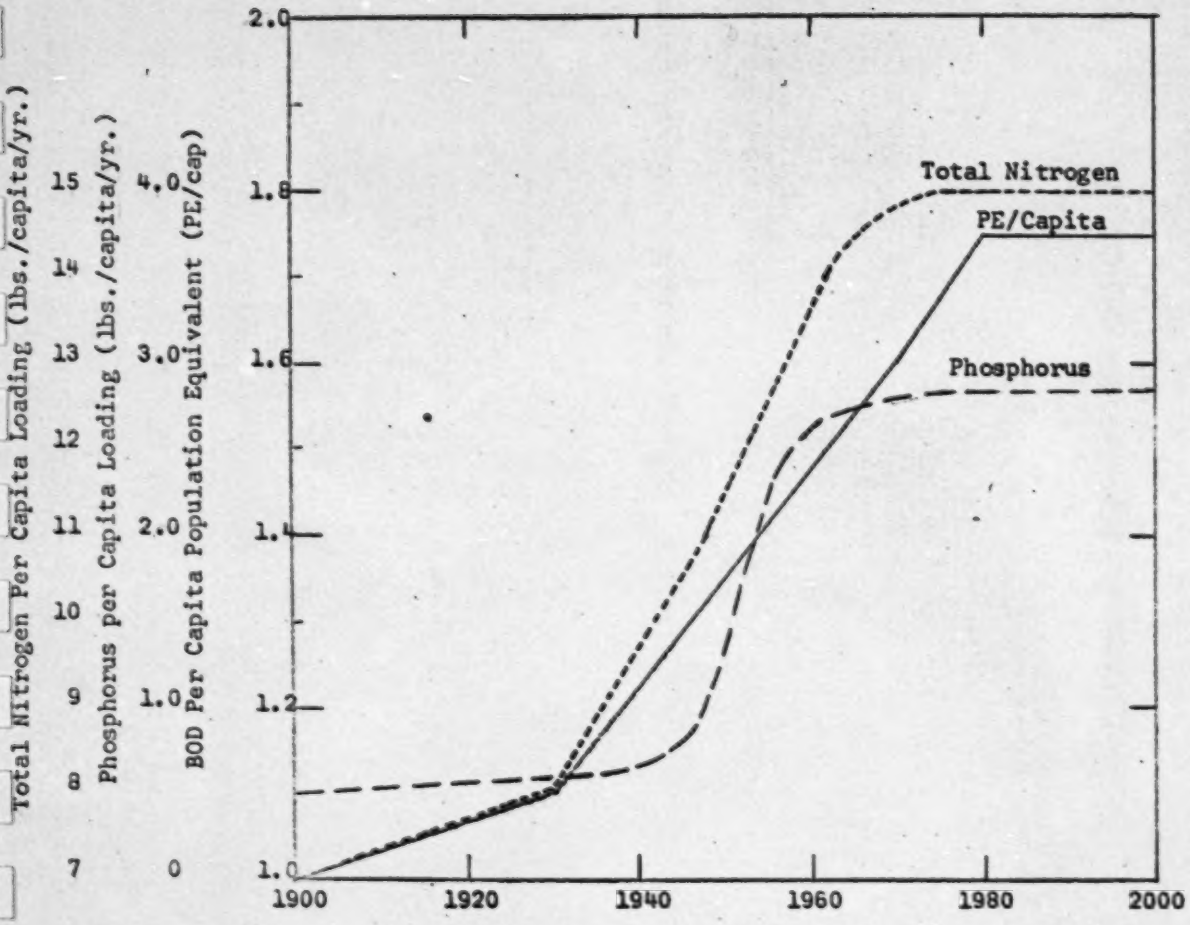

Figure 11

Variation in Per Capita Loadings in Raw Municipal Sewage for BOD, Total Nitrogen, and Phosphorus

APPENDIX A

TABLE 2

Municipal Primary and Secondary Treatment Removal Efficiencies and Fractions Remaining in Effluent (f) for BOD, Total Nitrogen, Phosphorus and Refractory Organics

Removal of:	No Treatment		Primary Treatment		Secondary Treatment	
	Percent Removal	f_o	Percent Removal	f_p	Percent Removal	f_s
BOD	0	1.0	35	.65	90	.10
Total Nitrogen	0	1.0	20	.80	50	.50
Phosphorus	0	1.0	10	.90	30	.70
Refractory Organics	0	1.0	20	.80	60	.40

The amount of phosphorus discharged to U. S. streams from municipal outfalls for any year, n, was estimated from the formula:

$$(\text{lbs. phosphorus discharged per year})_n = (P_p)_n [(SP)_{on} f_{oP} + (SP)_{pn} f_{pP} + (SP)_{sn} f_{sP}]$$

REFRACTORY ORGANICS

8) The category, Refractory Organics (RO), was assumed to be the difference between COD (Chemical Oxygen Demand) and BOD. The concentration of refractory organics in raw municipal sewage was assumed to be 100 mg/l. (350 mg/l. COD less 250 mg/l. BOD). Assuming a daily per capita municipal waste flow of 140 gallons, the annual refractory organics contribution, P_{RO}, would be: 30.4 lbs/capita-year. This value was assumed to be constant during the period 1900 and 2000 because information on historical trends was not available.

9) The assumed efficiencies of primary and secondary treatment in removing refractory organics are shown in TABLE 3. To establish these estimates, the following BOD and COD concentrations in raw sewage, primary effluent, and secondary effluent were assumed.

Concentration, mg/l.

	Raw	Primary	Secondary
COD	350	240	65
BOD	250	160	25
RO	100	80	40

The amount of refractory organics discharged to U. S. streams from municipal outfalls for any year, n, was estimated from the formula:

$$(\text{lbs. RO discharged per year})_n = (P_{RO})_n [(SP)_{on} f_{oRO} + (SP)_{pn} f_{pRO} + (SP)_{sn} f_{sRO}]$$

TABLE 3

ESTIMATED MUNICIPAL DISCHARGES OF BOD, TOTAL NITROGEN, PHOSPHORUS AND REFRACTORY ORGANICS TO U.S. STREAMS

Year	Sewered Population (millions)				P.E. Per Capita BOD	BOD Discharged (million lbs/yr.)			P_{TN} Per Cap. Nit. Contr. lb/yr
	Total	That discharges . . .							
		Raw $(SP)_{on}$	Prim. $(SP)_{pn}$	Sec. $(SP)_{sn}$		Raw	Prim.	Sec. Total	
1900	24.5^{4}	23.5^{4}	1.0^{10}	0^{10}	1.00	1430	40	0 1470	7.0
1910	34.5^{4}	30.5^{4}	4.0^{10}	0^{10}	1.03	1880	164	0 2050	7.0
1930	61.5^{4}	43.5^{4}	10.8^{10}	7.2^{10}	1.11	2940	435	49 3420	8.0
1940	70.1^{5}	29.4^{5}	18.4^{5}	22.3^{5}	1.23	2210	900	167 3280	9.6
1945	82.0^{6}	35.2^{6}	23.0^{6}	23.8^{6}	1.29	2770	1180	187 4140	10.5
1957	102.0^{7}	24.7^{7}	32.3^{7}	45.0^{7}	1.44	2170	1850	397 4420	13.2
1962	123.5^{8}	23.1^{8}	27.4^{8}	73.0^{8}	1.50	2120	1640	668 4420	14.4
1980	192.6^{9}	0	–	–	1.75	0	–	– –	15.0
1990	236.0^{10}	0	0	236.0	1.75	0	0	2520 2520	15.0
2000	279.4^{9}	0	0	279.4	1.75	0	0	2980 2980	15.0

cont'd on next page

TABLE 3 CONT'D

Year	Nitrogen Discharged (million lbs/yr.)				P_p Per Cap. Phos. Contr. lb/yr	Phosphorus Discharged (million lbs/yr.)				Refractory Discharged (million lbs/yr.)			
	Raw	Prim.	Sec.	Total		Raw	Prim.	Sec.	Total	Raw	Prim.	Sec.	Total
1900	165	5.5	0	170	.50	11.7	.44	0	12.1	715	25	0	740
1910	214	22.2	0	236	.50	15.3	1.80	0	17.1	930	98	0	1030
1930	348	69.5	28.6	446	.50	22.0	4.91	2.52	29.4	1320	264	86	1670
1940	282	142	107	531	.65	19.1	10.8	10.1	40.0	895	450	270	1620
1945	370	194	124	688	.80	28.2	16.6	13.3	58.1	1070	563	288	1920
1957	326	341	296	963	2.10	51.8	61.0	66.0	179	752	791	545	2090
1962	332	318	525	1180	2.40	55.5	59.5	123	238	703	677	887	2270
1980	-	-	-	-	2.60	-	-	-	-	-	-	-	-
1990	0	0	1770	1770	2.60	0	0	430	430	0	0	2870	2870
2000	0	0	2090	2090	2.60	0	0	508	508	0	0	3390	3390